Recent Technologies Usher in New Era of Coastal Geomorphology Research

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Research in the field of coastal geomorphology has been energized by the development of two new complementary high-spatial-resolution technologies: swath bathymetry sonar systems (SBSSs), and process-based numerical models (PBNMs) of hydrodynamics, sediment transport, and morphodynamics.

The combination and integration of the two should lead to rapid expansion of scientific understanding of the genesis and evolution of morphology in coastal regions, the accretion and erosion of coastlines, and the effects of climate change on fluvial systems, estuaries, and coasts. For example, dredging shipping channels and harbors, protecting coastal property from erosion, evaluating risks due to coastal flooding, and other chronic and enduring societal problems can now be approached with new optimism due to the high spatial resolution of SBSSs and PBNMs.

SBSS: Mapping With Unprecedented Detail

High-resolution SBSSs are a new measurement technology that is perhaps most significant to the field of coastal geomorphology. Through the systems' multibeam and side-looking echo sounders, which are mounted on ships and provide measurements of seafloor topography at spatial scales analogous to those obtained in airborne lidar and laser surveys of terrestrial topography, unprecedented detail of coastal morphology is being obtained. These state-of-the-art seafloor surveying instruments include sensor technology (e.g., a swath bathymetry sonar installed on a surface vessel and integrated with a highly accurate inertial motion reference unit, a Global Positioning System–based real-time kinematic navigation system, and in situ sound speed measurements) and processing software to apply corrections for dynamic attitude and environmental effects (e.g., sound speed, tides) to qualify each sounding with its total uncertainty.

SBSS mapping technology has steadily improved over the past 2 decades; current commercially available systems can measure continental shelf bathymetry with 100% spatial coverage at less than 1-meter horizontal resolution, with fewer ship tracks and at higher speeds than previously possible. The estimated depth uncertainty (accounting for the total propagated uncertainties) is usually better than 0.25% of water depth (see http://www.hydro-international.com/productsurvey/id5-Multibeam_Shallow_Water.html). Seabed features that were previously undetectable are now resolvable with SBSSs, and it has become possible to measure bathymetric change over time using repeated SBSS surveys. SBSSs can be enhanced with other instruments such as underwater video or water velocity profilers.

PBNM: Modeling Coastal Morphology With Unprecedented Spatial Resolution

A second technological advancement has been the development over the past decade of a new generation of PBNMs for coastal morphological evolution. PBNMs predict bathymetric change by accounting for the basic contributing physical processes of hydrodynamics, water waves, and sediment transport [e.g., *Lesser et al.,* 2004; *Warner et al.,* 2008]. The ability of increasingly powerful microprocessors to approximately solve the governing equations rapidly on a dense three-dimensional spatial grid has elevated the models to an impressive level of realism.

As research into the mechanics of the relevant physical processes progresses, there should be a corresponding improvement in modeling skill. For example, if geomorphic transport submodels that incorporate mechanistic landslide processes are developed for various geologic materials, these could be added to both coastal evolution and terrestrial landscape evolution models.

The Path Forward

The powerful combination of SBSSs and PBNMs, along with additional advances such as laser surveying, has enabled entirely new approaches to research in coastal geomorphology. In fact, it could be argued that the fields of geomorphology and Earth surface processes have been revolutionized through the development of airborne and terrestrial laser surveying (such as those used in the National Center for Airborne Laser Mapping), and process-based models for landscape evolution (e.g., the Community Surface Dynamics Modeling System).

PBNMs typically have powerful visualization tools capable of displaying both data and model predictions, so PBNM and high-resolution bathymetric/topographic measurements complement each other well, and their integration provides a quantitative means of evaluating model skill. In particular, repeated SBSS and laser surveys of the same area can provide measurements of bathymetric and topographic change, which is often the "answer" that PBNMs seek to predict. As quantitative measures of model skill are further refined and gain acceptance by the research community, the predictive skill level and uncertainty of PBNMs will become better quantified.

A Few Remaining Technical Challenges

Given the new capabilities for field measurements and numerical modeling, one might ask, What are the most significant remaining conceptual and technical barriers for the field of coastal geomorphology? Foremost among many are (1) the ability to measure bathymetry in very shallow water; (2) the ability to predict local sediment flux accurately; and (3) the inclusion of biological effects, or ecodynamics.

Measuring bathymetry in very shallow water is still quite difficult. Currently the complementary techniques of SBSS and laser surveying can provide high-resolution measurements of coastal geomorphology, including dunes and coastal cliffs, but neither of these is effective in most surf zones. Surf zones (the region hugging the coast where waves break) typically have rough waves, turbid waters, and strong currents that often render high-resolution bathymetric measurement unfeasible. GPS and single-beam echo sounders mounted on personal watercraft can successfully measure bathymetry across portions of the surf zone under common conditions, but these data are spatially sparse and labor intensive to obtain.

Although the nearshore surf zone is narrow in spatial scale and may represent a small geographic gap in data, obtaining data in this region is extremely important for research on shoreline change, coastal erosion, and coastal flooding due to tsunamis, hurricanes, or severe storms. Seamless high-resolution maps would provide new opportunities to investigate the interactions and morphological feedbacks of the complete coastal system.

The prediction of sediment flux is generally quite difficult and traditionally has been highly empirical, with each environment presenting its own particular features that challenge the application of broadly applicable principles. Further, predicting bathymetric change is predicated on the ability to predict gradients in sediment flux, a task that requires very demanding accuracies. Recent groundbreaking advances in the prediction of sediment flux include theories for sand transport using complex, two-phase (water and sediment) continuum mechanical approaches, but these approaches are currently far too computationally demanding to be used in high-spatial-grid-resolution numerical models.

Eventually, computational power for modeling sediment dynamics will enable the solution of further improved two-phase momentum and energy conservation equations on a spatial grid, but that day could still be a decade or more away. In the meantime, more efficient algorithms are required to capture the essential results of the full two-phase models. Even more challenging for sediment dynamics modeling is the complex reality that sediment is generally composed of grains of many sizes, shapes, and compositions, all of which, particularly for fine and organic sediments, profoundly affect the physics of sediment transport. With mixed sediments or broad size distributions, the vertical structure of grain characteristics within the seabed and the grain characteristics at the water-sediment interface in particular are crucial to the accurate prediction of sediment transport, and therefore need to be correctly accounted for in numerical models.

Successfully monitoring and predicting biological interactions with morphology will also be critical to better understanding shallow-water geomorphology. In many shallow-water environments, living systems interact significantly with morphodynamics, often with nonlinear and poorly understood feedbacks between the biology and the morphology. Simple examples include the production of organic sediment as a source of material to accrete the seabed, or the stabilizing effect of vegetation in tidal environments. More complex examples are the biological succession to be expected as a coastal environment changes characteristics due to rising relative sea level, such as has taken place in coastal Louisiana during the past century, and the effects of the biological evolution on coastal erosion, for example, in combination with a large storm such as Hurricane Katrina. Understanding the coupling between ecodynamics and morphodynamics, and incorporating these interactions into PBNMs, is an important and difficult challenge.

Beware the Limitations of PBNM and SBSS

One caution worth noting is that PBNM and SBSS capabilities are so advanced that their output products are often extremely visually appealing, and overinterpretation is tempting under the false assumption that these products are inherently correct and/or valuable. In fact, judicious choice and control of PBNM parameters, or integration and corrections of ancillary data in SBSSs, remain challenging enterprises even for the most skilled practitioners. Further, although SBSSs can provide remarkable and stunning images of the seafloor, it may not always be in the best interest of a coastal state or municipality to invest its limited resources in collection of these data. For example, existing data may be adequate for resource management and decision-making needs, or the regional problems may be centered on the shallow nearshore region where, as described above, SBSSs are typically not capable of collecting adequate data under many conditions.

Nonetheless, the remarkable capabilities of SBSSs, laser surveying, and PBNMs provide optimism to approach the challenges that lie ahead for the field of coastal geomorphology research (and Earth surface process research in general) with high expectations. Accurate and high-resolution measurements of submerged bathymetry and terrestrial topography provide the input boundary conditions and often the output goal for Earth surface process models. The biggest challenge remaining is to discover, explain, and incorporate physical and biological processes that will enable PBNMs to ultimately make predictions with quantifiable uncertainties.

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